Cold Electronics and Ionization Charge Extraction in the MicroBooNE LArTPC

New Perspectives 2018

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μBooNE

BROOKHAVEN NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

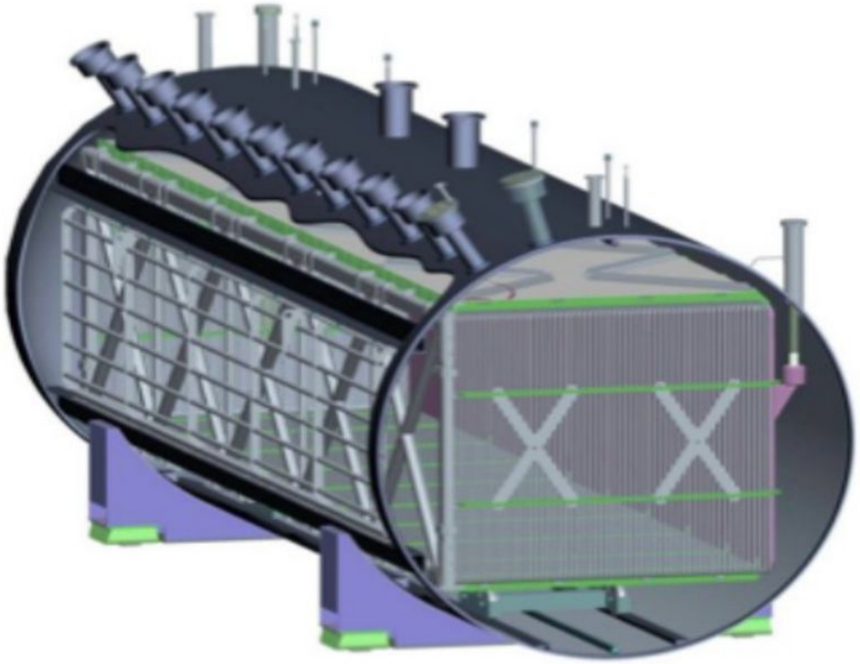
- What is the MicroBooNE LArTPC?
- What are cold electronics and why is the MicroBooNE detector using them?
- MicroBooNE’s cold electronics have excellent performance
- Crash course in LArTPC signals,MicroBooNE field response data/MC
- MicroBooNE ionization charge extraction
- Summary

What is MicroBooNE?

Micro Booster Neutrino Experiment

- First large-scale US Liquid Argon Time Projection Chamber (LArTPC)
- LAr active target 85 tons (170 total)
- First large scale application of cold front-end electronics in LArTPCs
- Exposed to short baseline neutrino beam produced at Fermilab
- Taking neutrino data since Oct 2015!

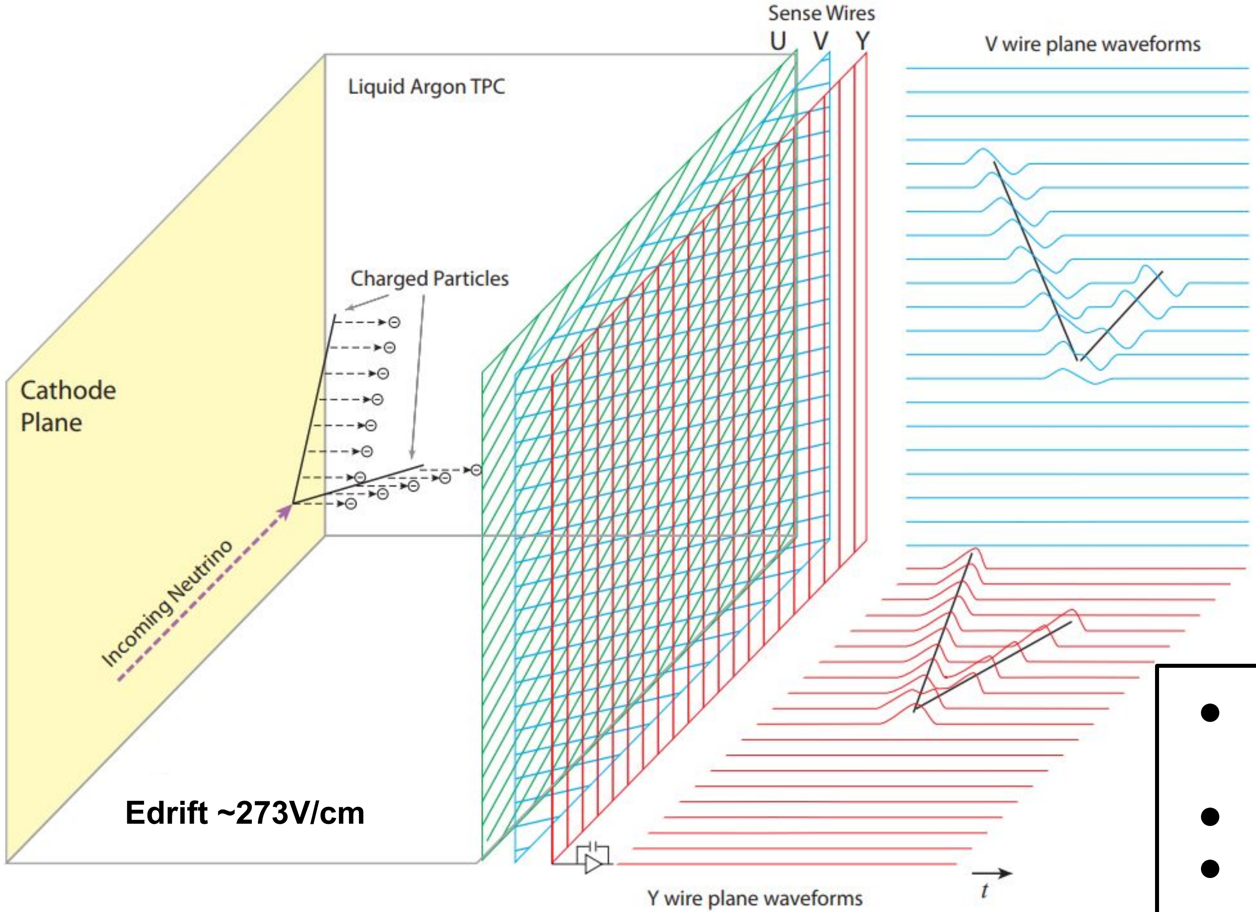
MicroBooNE Cryostat



Physics Goals

- Investigate MiniBooNE excess
- Neutrino-Ar cross-sections
- LArTPC Detector R&D

MicroBooNE is a Single-Phase LArTPC



Edrift ~273V/cm

- LArTPC concept suggested in 1974
- Large fully active liquid argon target for neutrino interactions, tracker and calorimeter
- Pioneered by ICARUS, more recently ArgoNeut, **MicroBooNE**, others

- **Two wire planes (U/V) sense induced charge,**
- **Third Y-plane collects charge**
- **3mm wire pitch, expect position resolution ~1mm**

MicroBooNE LArTPC R&D and Signal Processing

- Multiple MicroBooNE publications focused on technical details of LArTPC performance, signal processing (focus of this talk):
- **Noise Characterization and Filtering in the MicroBooNE Liquid Argon TPC**
  - JINST 12 P08003
  - MicroBooNE electronic noise mitigation and performance
- **Ionization Electron Signal Processing in Single Phase LArTPCs I. Algorithm Description and Quantitative Evaluation with MicroBooNE Simulation**
  - Simulation of MicroBooNE LArTPC and evaluation of performance of novel charge extraction algorithms with simulated data
- **Ionization Electron Signal Processing in Single Phase LArTPCs II. Data/Simulation Comparison and Performance in MicroBooNE**
  - Validation of MicroBooNE simulation and evaluation of performance of novel charge extraction algorithms with MicroBooNE data

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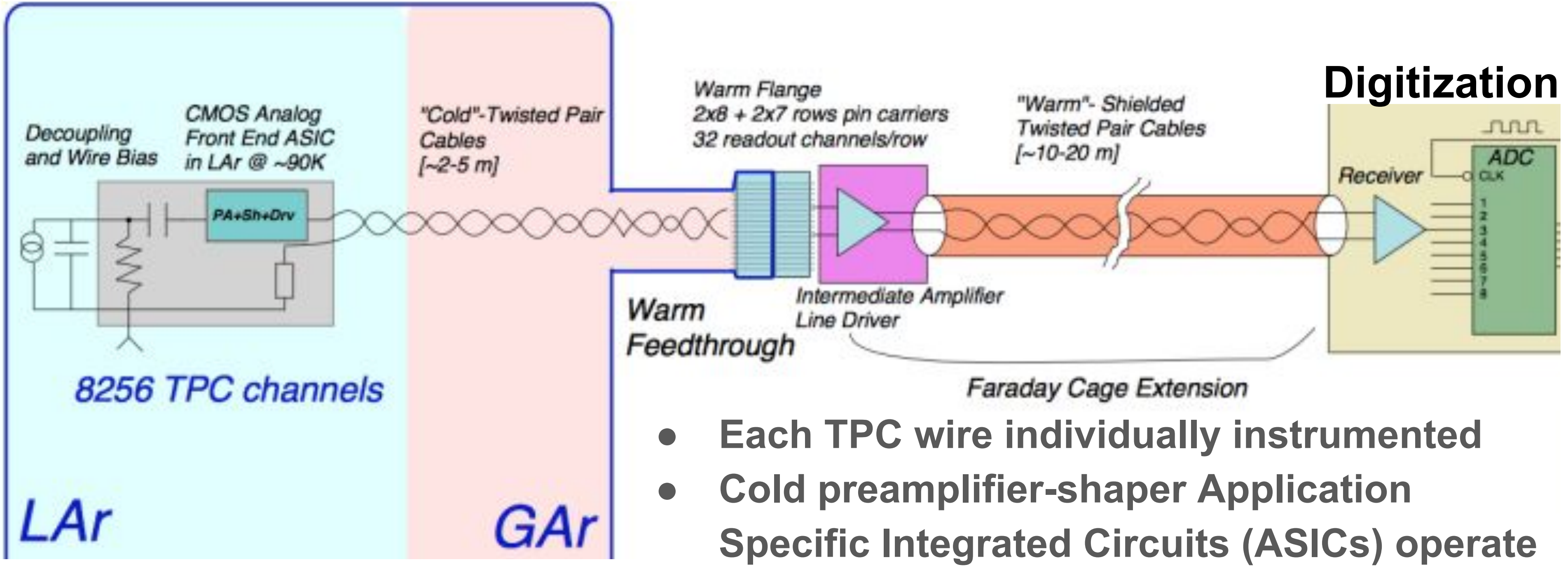
MicroBooNE Uses Low Noise Cold Electronics



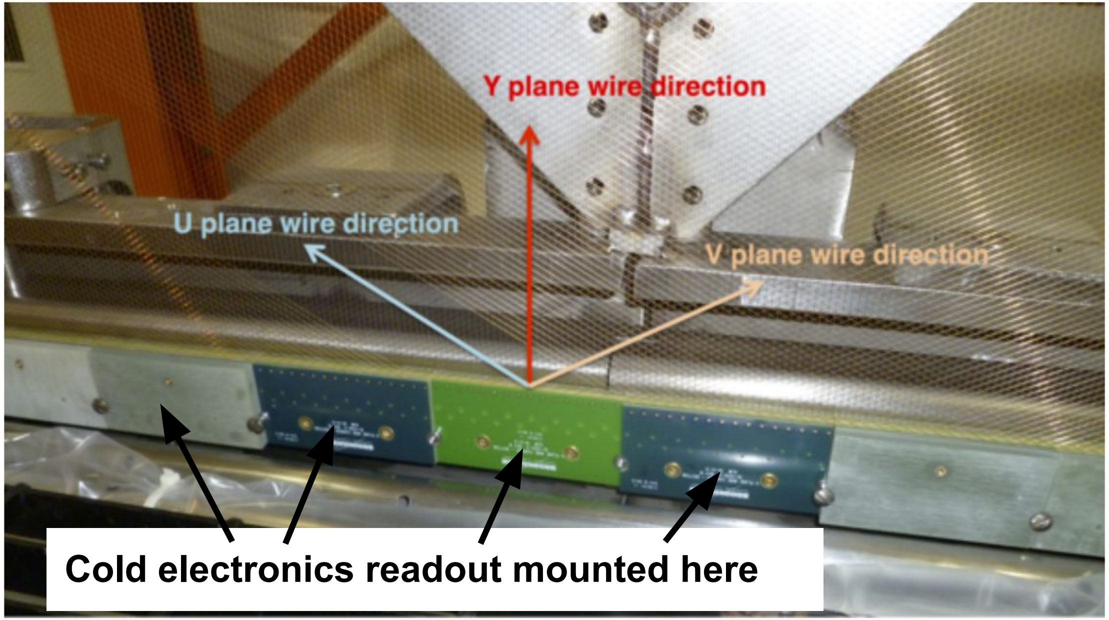
Cryostat
Wires + Cold Electronics

- **Each TPC wire individually instrumented**
- **Cold preamplifier-shaper Application Specific Integrated Circuits (ASICs) operate inside the cryostat at LAr temperature**
- **Cold electronics simplify cryostat design and optimize LArTPC performance**

MicroBooNE LArTPC and Wire Planes

MicroBooNE LArTPC with Wire Planes + Cold Electronics Installed

Installed MicroBooNE Wires with Wire Plane Orientation Indicated



- MicroBooNE uses three wire-planes to detect drifted ionized charge
- Two planes (U/V) sense charge by induction, directly collected by third plane (Y)

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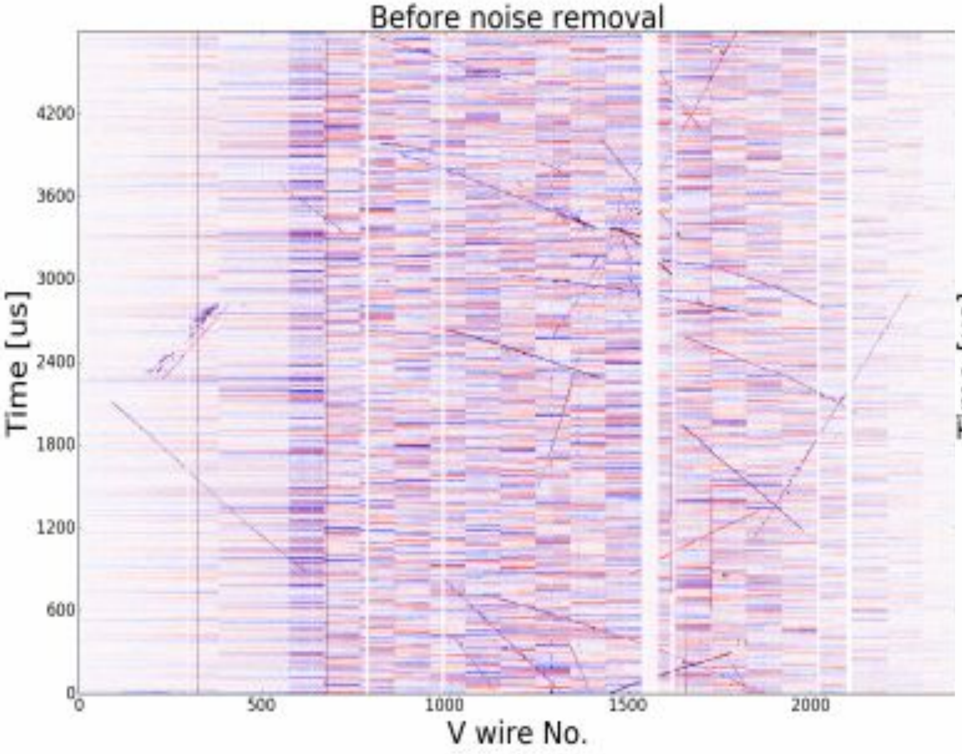
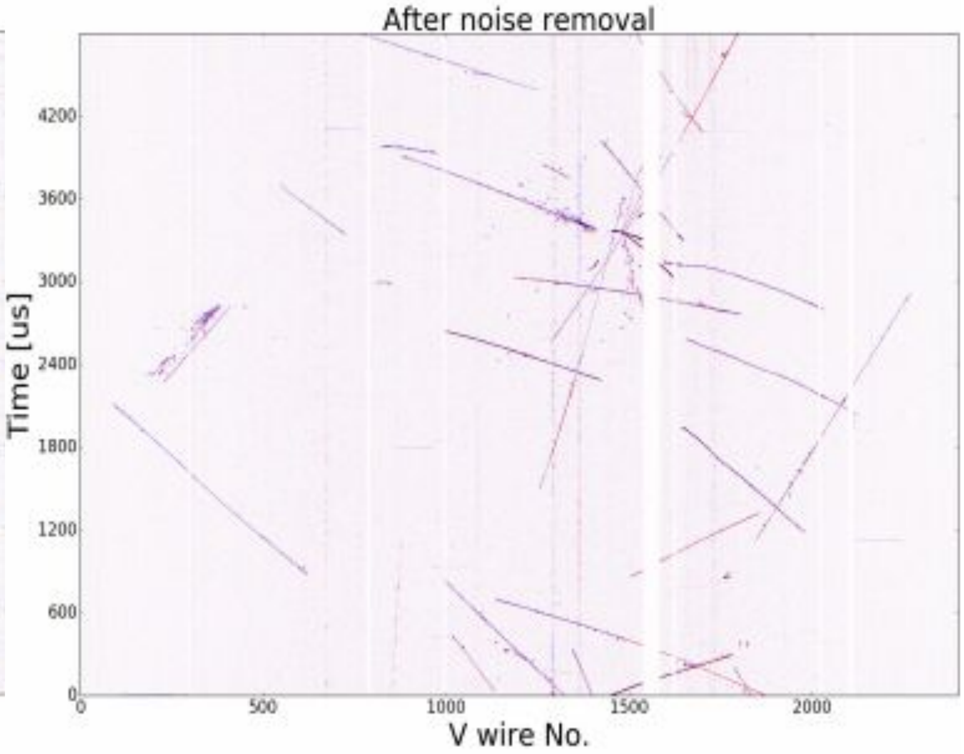
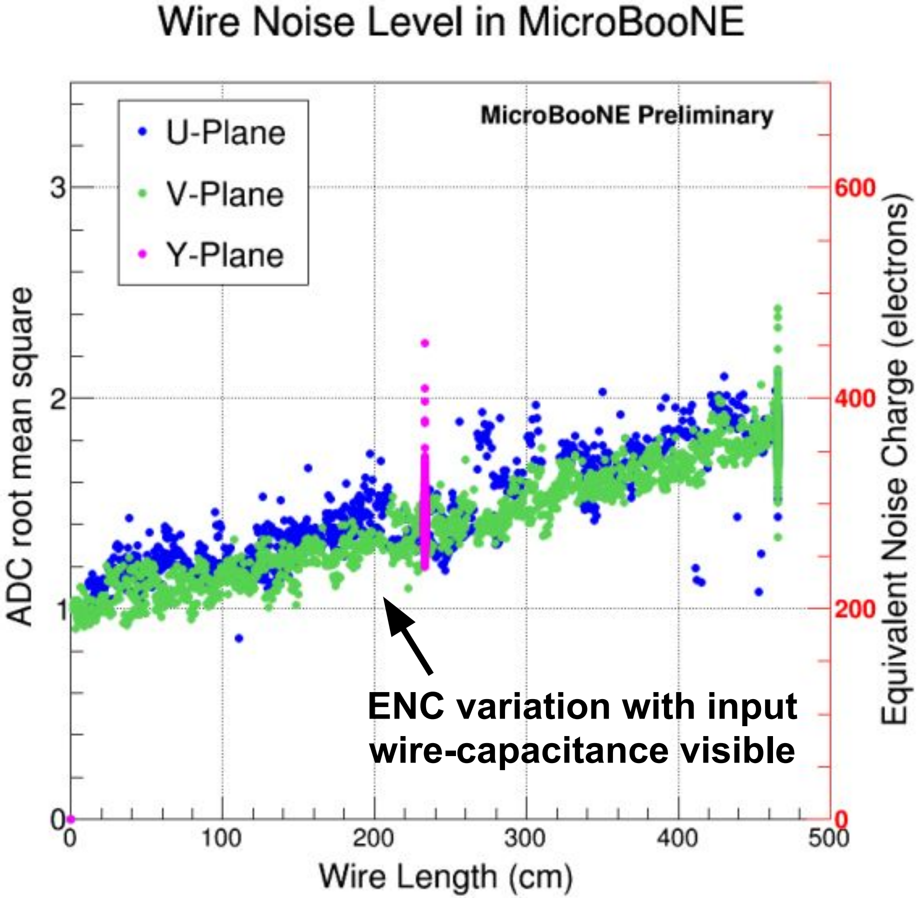
MicroBooNE Event Display Pre/Post Noise Filtering





Significant improvement after noise filtering,
obtain "bubble chamber" quality interaction images

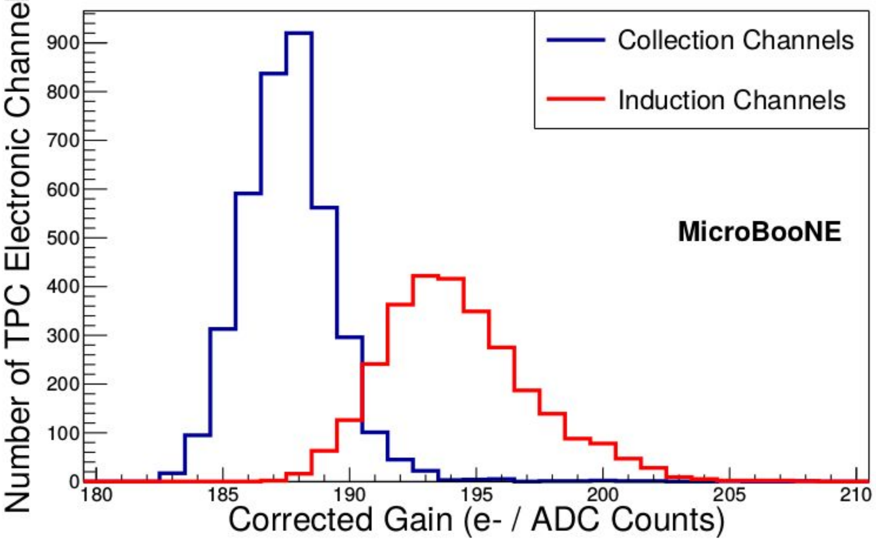
MicroBooNE Cold Electronics Noise Performance



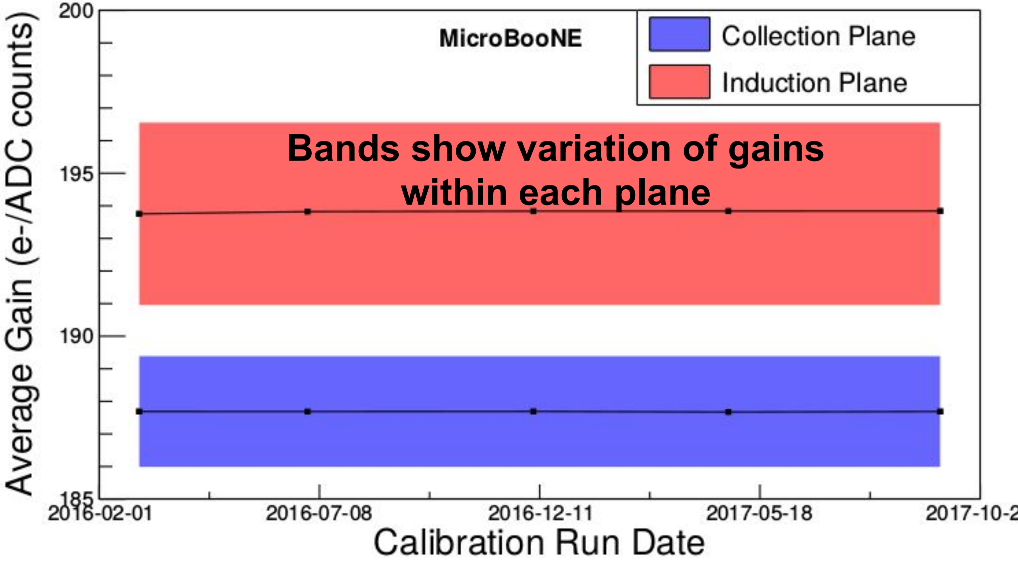
Excellent cold electronics performance (ENC <420e-) post-filtering!

MicroBooNE Cold Electronics Response is Stable

Overall Channel Gain Distribution



Mean Collecton + InductionChannel Gain Vs Time



- TPC channel electronic gains measured in-situ using nominal response function
  - Corrections applied to account for implementation of calibration system
  - Mean induction gain is 194.3 ± 2.8 [e − /ADC], Mean collection gain is 187.6 ± 1.7 [e − /ADC]
- **Cold electronics gain stable over two year period,variation ~0.2%**

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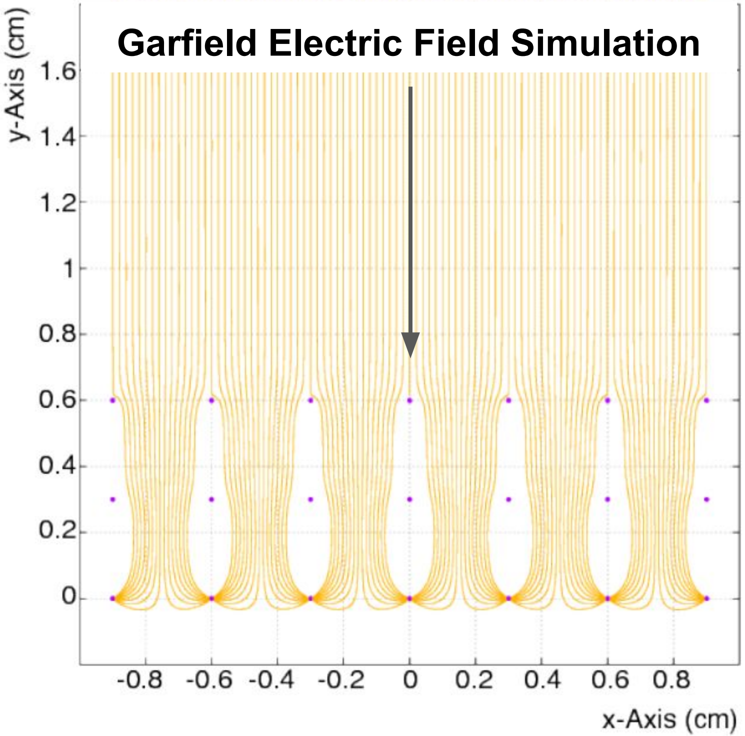
MicroBooNE LArTPC Wire Response



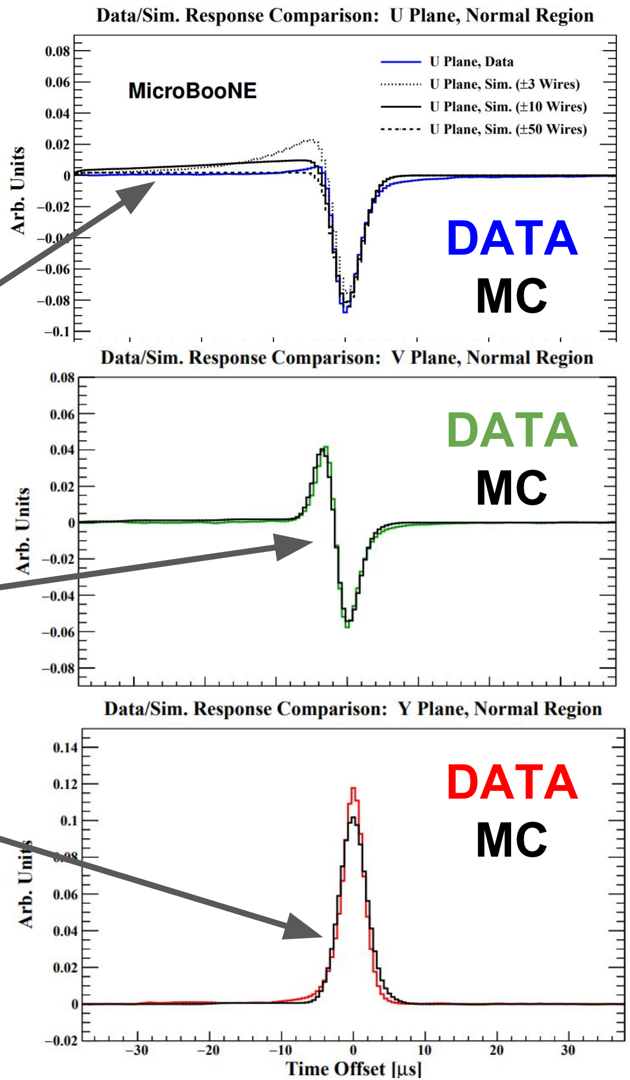
Ramo's Theorem

$$i = -q\vec{E}_w \cdot \vec{v}_q$$

U-Plane

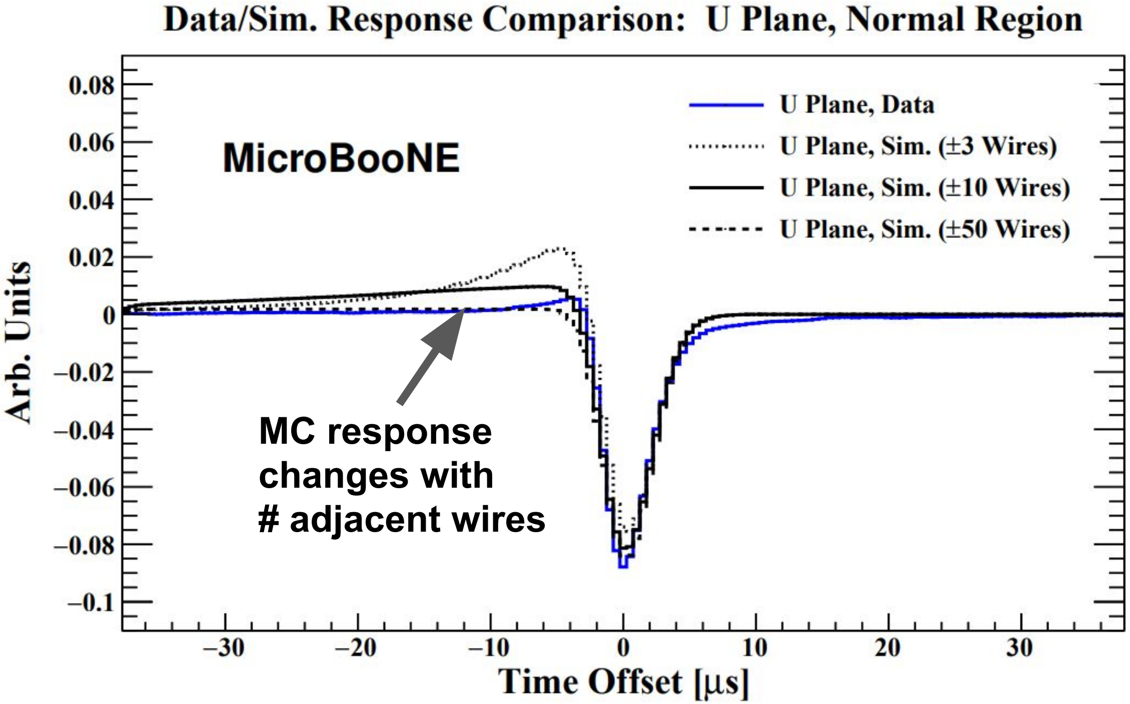
V-Plane

Y-Plane



- Ionized electrons from tracks drift to anode sense wires
- Induces current on wires following Ramo's Theorem
- **Different response on each wire-plane reproduced by detailed simulation, <u>response is understood</u>**

Wire Response and Long-Range Induction



- Long-range induced current **significantly** changes induced response shape
- Can reproduce this effect in simulation, improve data/MC agreement by increasing number of simulated adjacent wires: **effect is understood**

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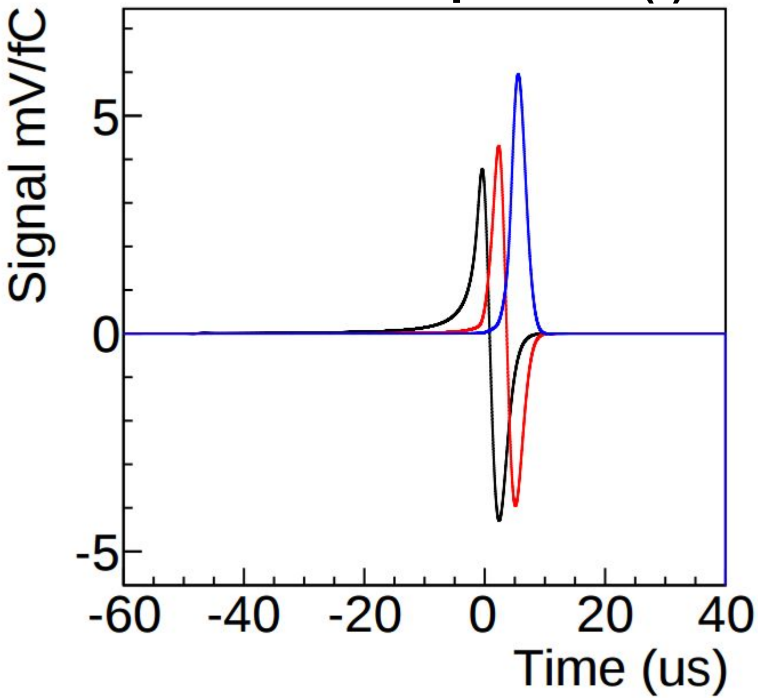
Ionization Charge Extraction and Deconvolution

- Cold electronics and wire response is well understood, how to apply?
- Recover ionization charge by deconvoluting waveforms with known detector response

Detector Response R(t)



Time Domain, Measured Signal as Convolution of Charge and Response

$$M(t_0) = \int_{-\infty}^{\infty} R(t, t_0) \cdot S(t) \cdot dt$$

Convert to Frequency Domain

$$M(\omega) = R(\omega) \cdot S(\omega)$$

Recover Charge Signal from Deconvolution

Deconvolution filter

$$S(\omega) = \frac{M(\omega)}{R(\omega)} \cdot F(\omega)$$

2D-Response Accounts for Long-Range Induction

1D Response

$$M(t_0) = \int_{-\infty}^{\infty} R(t, t_0) \cdot S(t) \cdot dt$$

Wire i Observed Signal

2D Response

$$M_i(t_0) = \int_{-\infty}^{\infty} (\ldots + R_1(t_0 - t) \cdot S_{i-1}(t) + R_0(t_0 - t) \cdot S_i(t) + R_1(t_0 - t) \cdot S_{i+1}(t) + \ldots) \cdot dt$$

Contribution from charge on wire i - 1

Contribution from charge on wire i

Contribution from charge on wire i + 1

- Long-range induction **significantly** changes response shape
- Need to generalize response to account for contributions from adjacent wires

Extend Deconvolution Method to 2D

1D Response in Frequency Domain

$$M(\omega) = R(\omega) \cdot S(\omega)$$

Observed Signal in Frequency Domain

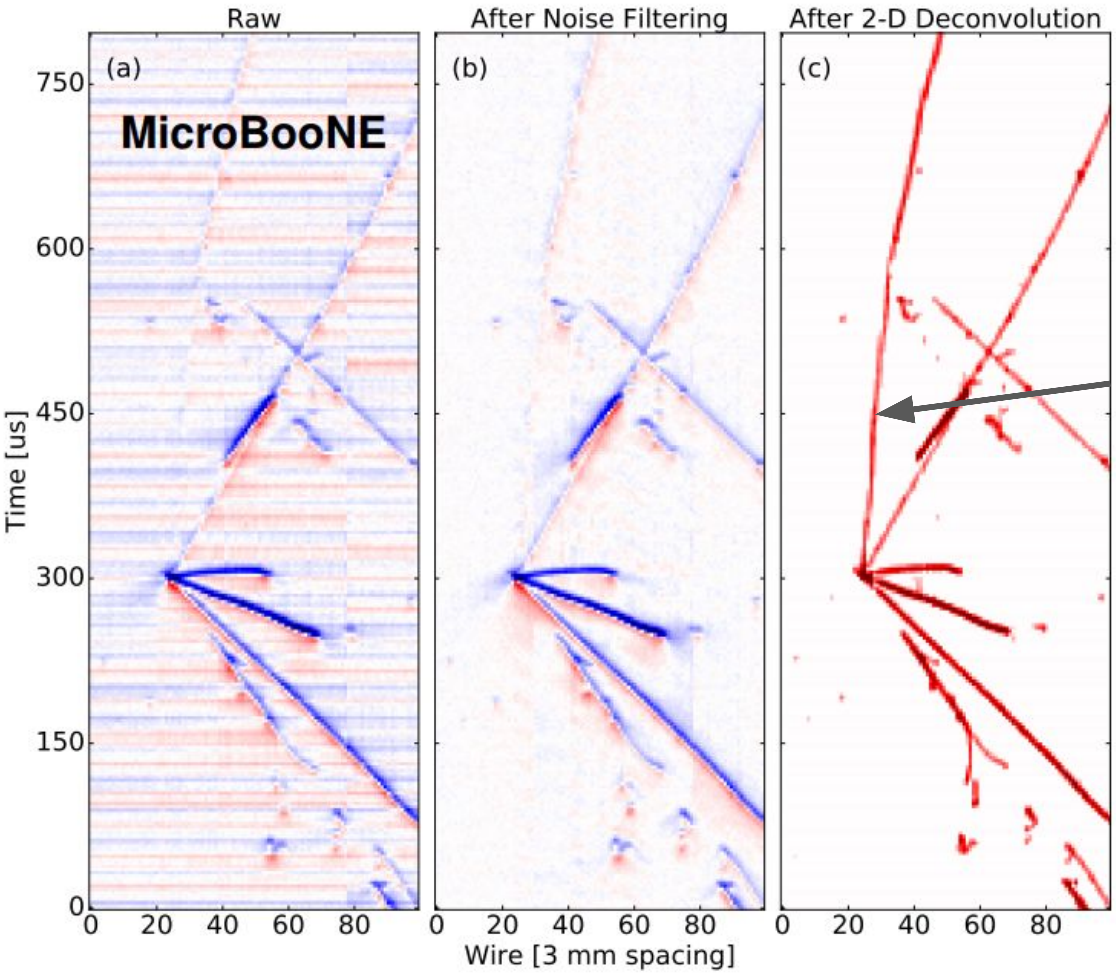
2D Response in Frequency Domain

Wire Charge in Frequency Domain

$$\begin{pmatrix} M_1(\omega) \\ M_2(\omega) \\ \vdots \\ M_{n-1}(\omega) \\ M_n(\omega) \end{pmatrix} = \begin{pmatrix} R_0(\omega) & R_1(\omega) & \ldots & R_{n-2}(\omega) & R_{n-1}(\omega) \\ R_1(\omega) & R_0(\omega) & \ldots & R_{n-3}(\omega) & R_{n-2}(\omega) \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ R_{n-2}(\omega) & R_{n-3}(\omega) & \ldots & R_0(\omega) & R_1(\omega) \\ R_{n-1}(\omega) & R_{n-2}(\omega) & \ldots & R_1(\omega) & R_0(\omega) \end{pmatrix} \cdot \begin{pmatrix} S_1(\omega) \\ S_2(\omega) \\ \vdots \\ S_{n-1}(\omega) \\ S_n(\omega) \end{pmatrix}$$

- Extend the deconvolution procedure to 2D
- **Big picture: 2D-deconvolution improves ionization charge extraction from induction wires by accounting for long-range induction**

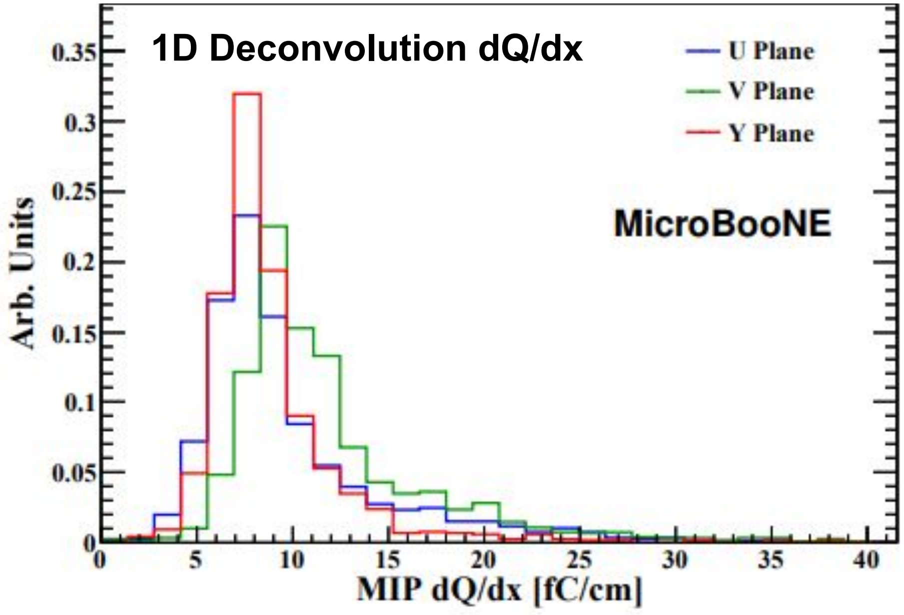
MicroBooNE Event Display After 2D-Deconvolution

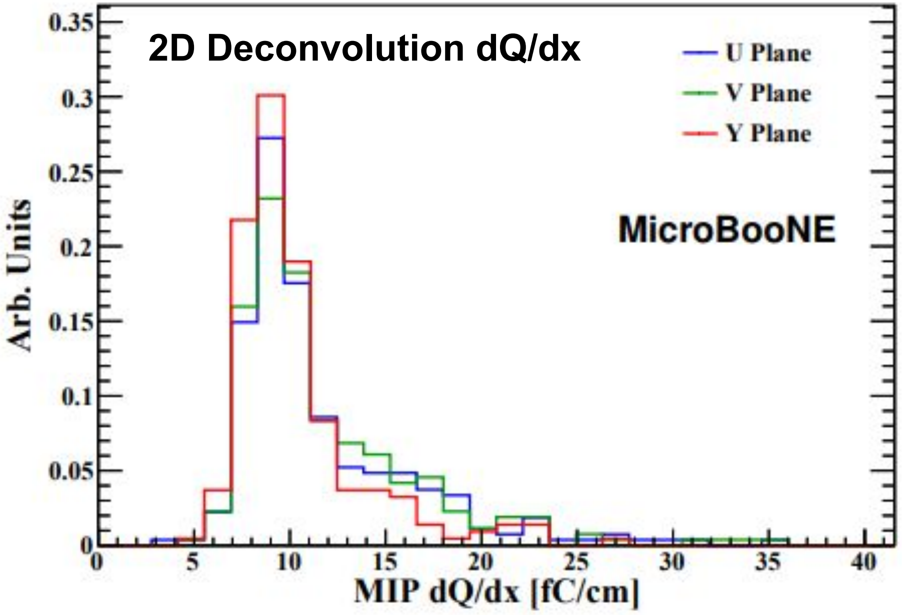


Previously obscured features recovered by 2D-deconvolution

2D-deconvolution is enabled by superior noise performance of cold electronics

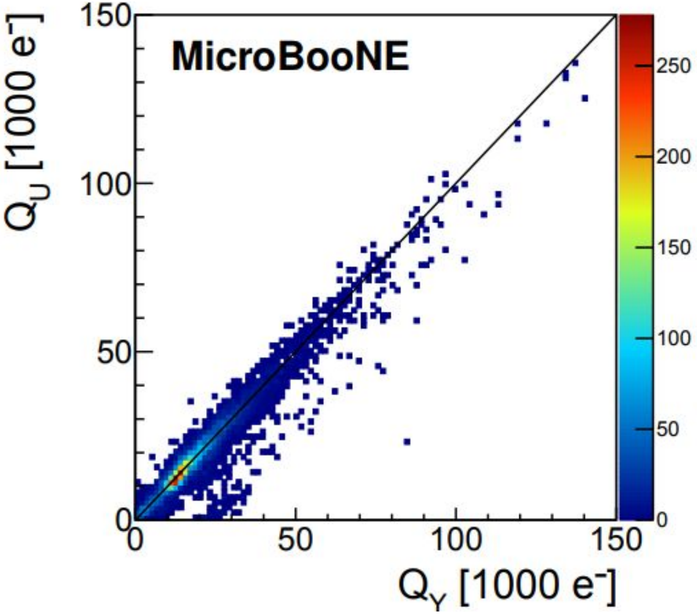
Cosmic Muon dQ/dx Measurements Improved by 2D-Deconvolution

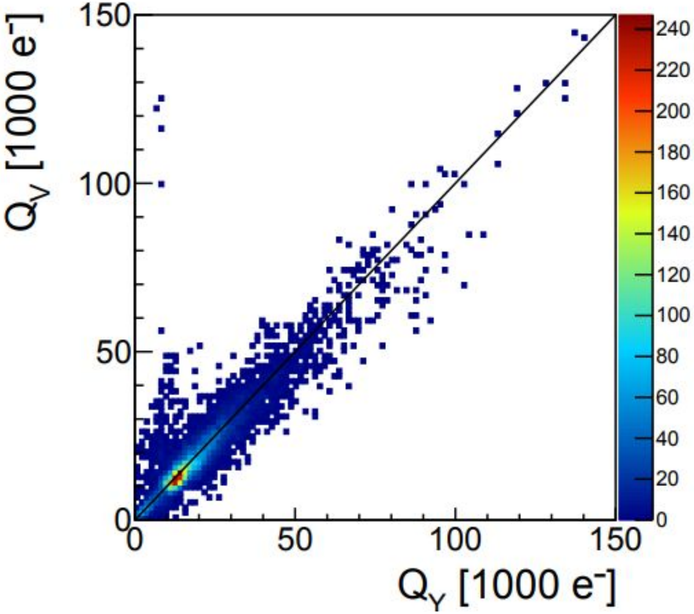




- 2D-deconvolution improves agreement between plane dQ/dx measurements
- **Puts induction and collection planes on the same footing!**

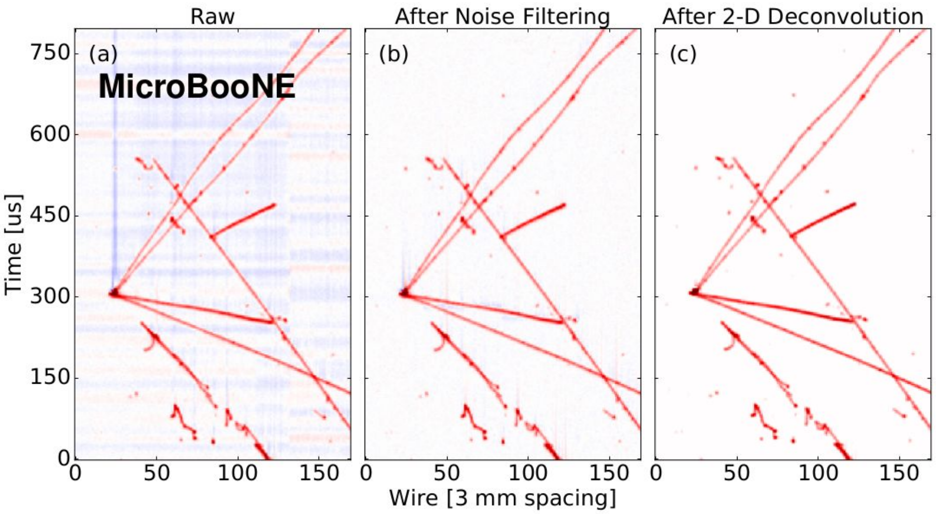
Cosmic Muon Induced Charge Measurements Match Between Wire Planes

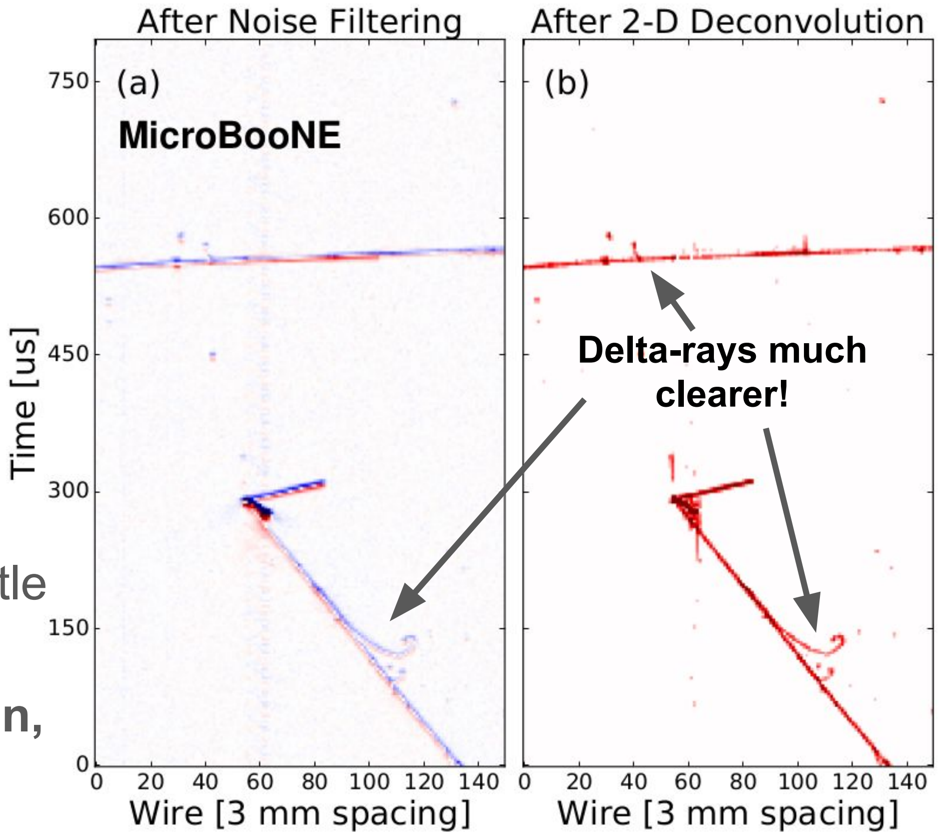




- Accurate charge matching across LArTPC wire planes has been demonstrated for the first time!

More Improved Event Displays!





- Improved signal processing reveals subtle features in neutrino interactions
- **Expect improvement in reconstruction, supporting physics goals**

Summary

- MicroBooNE has achieved excellent cold electronic noise levels
- Low noise allows novel deconvolution-based ionization charge extraction methods that correctly account for long-range induction
- Demonstrated first accurate charge matching across LArTPC wire planes
- Detailed understanding of MicroBooNE detector response is crucial for the development of physics analyses and evaluation of systematic uncertainties
- Improve the reconstruction of neutrino interactions

Backup